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Business process management system such as workflow management system has attracted increasing research attentions in e-commerce, especially from an inter-organizational workflow perspective. When designing inter-organizational workflow, it is important to consider soundness of the workflow, which identifies whether a workflow terminates properly. The principle of local criteria ensuring global soundness can be applied to allow the soundness of the entire inter-organizational workflow to be achieved without knowing the detail workflow of every participating organization. However, this principle sometime can become too restrictive when we attempt to ensure the overall workflow is sound while changes are made to the workflow. It is not always easy to reach a balance between achieving soundness and flexibility. This paper presents an approach to make the public-to- private approach more flexible by proposing a weakly equivalence concept in an inter- organizational workflow context that can function as a local criterion.

Disciplines

Arts and Humanities | Social and Behavioral Sciences

Publication Details

Liang, G. & Lau, S. K. 2007, 'Towards more flexible internal workflow change: weakly equivalence concept for inter-organizational workflow design', CEC/EEE 2007: 9th IEEE International Conference on E-Commerce Technology and the 4th IEEE International Conference on Enterprise Computing, E-Commerce, and E-Services, IEEE, IEEE Xplore, pp. 141-148.

Towards More Flexible Internal Workflow Change: Weakly Equivalence Concept for Inter-organizational Workflow Design

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Abstract

Business process management system such as workflow management system has attracted increasing research attentions in e-commerce, especially from an inter-organizational workflow perspective. When designing inter-organizational workflow, it is important to consider soundness of the workflow, which identifies whether a workflow terminates properly. The principle of local criteria ensuring global soundness can be applied to allow the soundness of the entire inter-organizational workflow to be achieved without knowing the detail workflow of every participating organization. However, this principle sometime can become too restrictive when we attempt to ensure the overall workflow is sound while changes are made to the workflow. It is not always easy to reach a balance between achieving soundness and flexibility. This paper presents an approach to make the public-to-private approach more flexible by proposing a weakly equivalence concept in an inter-organizational workflow context that can function as a local criterion.

1. Introduction

Business process management system such as workflow management system has attracted increasing research attentions in e-commerce, especially from an inter-organizational workflow perspective [5, 6, 7, 8, 11, 13, 15, 16]. They are characterised by process, information, resource and task [3]. The process perspective which describes the control flow, i.e. the ordering of tasks, is the most important. In investigating this perspective, one of the theoretical issues that is crucial in inter-organizational workflow system is the *soundness* issue [1]. A sound workflow means a process can terminate properly with no deadlock. The simplest way to verify soundness of a workflow system is to require all processes to be declared to all

participants in the system. However this is impractical in business environment, in particular one that crosses the boundaries of more than one organization, due to unwillingness of business partners to publish details of their business processes and operations. Therefore the ability to support flexible changes to business process management system is important when dealing with increasingly complex business processes, in particular systems integration across different organizations.

One of the basic principles that had been proposed to address the issue of inter-organizational workflow design and soundness verification is the “local criteria for global soundness” principle [12]. A local criterion refers to one that can be verified locally without the need to know detail of each component in an inter-organizational workflow. In this case as long as all the sub-workflows are sound and follow the local criteria separately under specified conditions, the whole workflow combined with these sub-workflows are guaranteed to be sound. This way, it makes it possible to achieve global soundness of the entire inter-organizational workflow without exposing all private workflows to every participant [12]. Several approaches have been proposed based on this principle in the literature [2, 4, 9, 12, 17]. One of these workflow design approaches is the public-to-private (P2P) approach [4], in which the concept of branching bisimilarity [10] is considered as the local criterion in the P2P approach [4]. However, this method of local criterion can sometimes become too restrictive when direction of message exchange across organizations is not taken into account.

This paper investigates way to improve the P2P approach to make it more flexible. Firstly, soundness verification methods will be discussed. Then the concept of local criteria ensuring global soundness in the inter-organizational workflow design will be presented. Next we present an innovative way to improve the local criterion in the

P2P approach so that more flexible inter-organizational workflow is possible.

2. Local criteria for global soundness principle for inter-organizational workflow design

To clarify the term inter-organizational workflow, we refer it as workflow on two or more workflow management systems. Before we can effectively discuss workflow design, we will first need to have a way to evaluate the design. Soundness and privacy of a workflow implementation are two factors which we will consider here. Soundness is a basic requirement for a workable workflow based on the workflow-net model [1]. A sound workflow refers to a workflow that can always reach *proper termination* and contain no dead transition. Informally, a *dead* transition is a useless activity in a workflow net model.

The verification of soundness for both workflows within an organization and in an inter-organizational workflow environment can be done automatically using analytic techniques of Petri net such as liveness and boundedness verification [1, 2]. However, this method requires full definition of the entire workflow. As a result, the problem of achieving soundness of an inter-organizational workflow becomes more difficult when participants are not willing to reveal their internal workflows. Therefore, how to design a sound workflow without exposing unnecessary private information has become an increasingly important and practical problem in the B2B environment.

To address the issues of *soundness* and privacy at the same time, one of the ways proposed to address this issue is the “local criteria for global soundness” principle [12]. The principle states that when a number of sound sub-workflows are organized together following a specific local criterion, the global soundness of the entire workflow is ensured. There are several advantages in applying this principle. Firstly, since global soundness comes with local criteria, all business partners no longer need to expose or reveal details of their private workflows for soundness verification. In this case, what is required is to check if their private workflows have satisfied the local criteria. This addresses the privacy issue. Secondly, when one or more business partners want to modify their private workflows according to their own business needs, such local criteria can provide a guideline to make sure the modification does not affect the global soundness. Finally, when new business partners need to be brought into an inter-organizational workflow, the local criteria principle makes it possible to keep the entire

workflow sound and minimize the coordination with every existing business partners at the same time. This way it makes B2B cooperation more flexible. In the literatures, several approaches based on this principle have been proposed [2, 4, 9, 12, 17]. Although not all of them result in all the above benefits, the results reported in the literatures still allow us to understand more about the relation between sub-workflows and the overall workflow and make it easier to design a sound inter-organizational workflow.

Several local criteria proposed in literatures are described as follows. A natural way to propose a local criterion is to distinguish between public workflows and private workflows first, and then prove that if all the private workflows are consistent with the public workflow in some ways, then the overall workflow is sound. van der Aalst’s approach follows this intuition [2]. It is based on a workflow model using Petri net and message sequence diagram. Firstly, a *workflow net* model using Petri net concept is used to describe the private workflow. Then synchronous and asynchronous messages connecting different organizations are modeled using message sequence diagram. Using such a model, a consistency criterion is proposed to decide if a private workflow presented by the Petri net can work with the public workflow presented by the message sequence diagram. Unfortunately, it is very difficult to even define the criteria in a situation when there is more than one message sequence charts involved, which is common in practice. As a result, only situation called *l-consistent*, corresponding to situation when only one message sequence chart is involved can be considered. Thus it is too restrictive. Kindler et al. [12] proposed a similar but more comprehensive approach based on the concept of scenarios, which is similar to the concept of a message sequence chart. This approach is able to deal with situation when more than one scenario is involved. van Glabbeek & Stork [9] proposed another local criterion with the concept of *query nets*, which does not need the notion of a public workflow. This approach is restrictive in another way: the messages exchanged among different private workflows need to be organized as pairs of input and output places. However, it is not always easy to transfer a complex interaction between two organizations into pairs of input/output messages. The approach proposed by Wombacher et al. [17] does not need the notion of a public workflow either. It was inspired by the appearance of Web services technique. Web services architecture provides a mechanism to enable publishing and searching for a single Web service, thus it is useful when an organization wants to outsource part of its workflow. However when two organizations want

to integrate their workflows seamlessly, this mechanism of Web services is not enough. The flow logic of the workflows involved should also be able to be published and searched. Wombacher et al. [17] propose a match making mechanism based on a revised version of Finite State Automata model to decide whether two workflows are compatible to work together. Using this method, it is easier for two organizations to establish business relations without relying on manual negotiation for the specification of the public workflow. P2P approach in [4] is considered as another approach following the local criteria principle. This approach is the focus of this paper and will be discussed further in the next section.

3. An improved local criteria for a more flexible P2P approach

From the discussion above, we can see that local criteria play a very important role in most workflow design approaches. Without such a method of local criteria ensuring global soundness, soundness verification requires all participants to reveal their workflow details after any modification is made to any part of the workflow. However, a local criterion sometimes can become too restrictive when we try to protect the soundness of the entire workflow from changes. At the same time it prevents possible workflow modification without affecting the overall soundness of the entire workflow. It is not always easy to achieve a balance between guaranteeing soundness and flexibility.

In this paper, we focus on the P2P approach [4]. The P2P approach contains three steps. Firstly, the public part of the inter-organizational workflow is created. Secondly, the public workflow is partitioned over the organizational entities involved. Finally, for each organizational entity, a private workflow that is a subclass of the relevant part of the public workflow is created using the concept of projection inheritance. According to van der Aalst [4], the resultant inter-organizational workflow using this approach is guaranteed to be sound. Furthermore, as the public workflow is designed before the private workflow is created, it is not necessary to consider the issue of keeping the internal workflow secret. As long as the private workflow is a subclass of their relevant part of the public workflow under the concept of projection inheritance, the organizations involved in the inter-organizational workflow can design and modify their internal private workflows in any way they want, and it is not necessary to be concerned with the soundness of the entire inter-organizational workflow.

Workflow inheritance is a concept derived from the concept of branching bisimilarity. In the P2P

approach, branching bisimilarity and projection inheritance can be viewed as the local criteria. Branching bisimulation refers to a relation between two marked labeled place/transition nets (P/T-net). Generally speaking, if two marked, labeled P/T-nets are branching bisimilar, it means that anyone of them can simulate every step of the observable behaviour of the other after executing zero or more silent actions. At the same time, workflow inheritance refers to a subclass of a workflow under projection inheritance can simulate any behavior of its super class after hiding all the new methods added in the subclass. Formal definition of branching bisimilarity and projection inheritance can be found in [4]. As explained in [4], the moment when a choice is made is an important factor needed to be considered when making changes to a sub workflow, and this is the major reason why branching bisimilarity is used in the P2P approach in [4]. Figures 1 and 2 present an example. In Figure 1, an inter-organizational workflow involving a customer and a retailer is given to show a scenario as follows. Firstly, the customer sends an order to the retailer. Then retailer decides to confirm or decline the order by responding an order confirmation or order decline message. If it is an order confirmation message, the customer sends payment and receives product. Otherwise, the workflow goes to an end. In Figure 1, the customer sub workflow on the left and the retailer sub workflow on the right are divided by a dotted line.

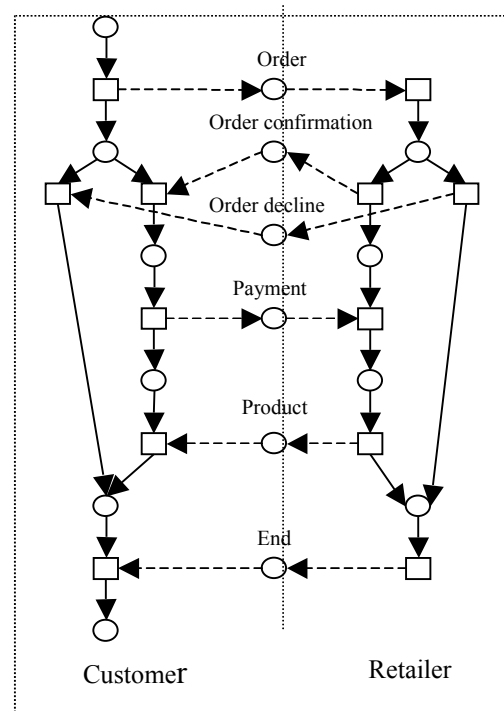


Figure 1. An inter-organizational involving two organizations.

In Figure 2, a change to the sub workflow of the customer makes the overall workflow unsound.

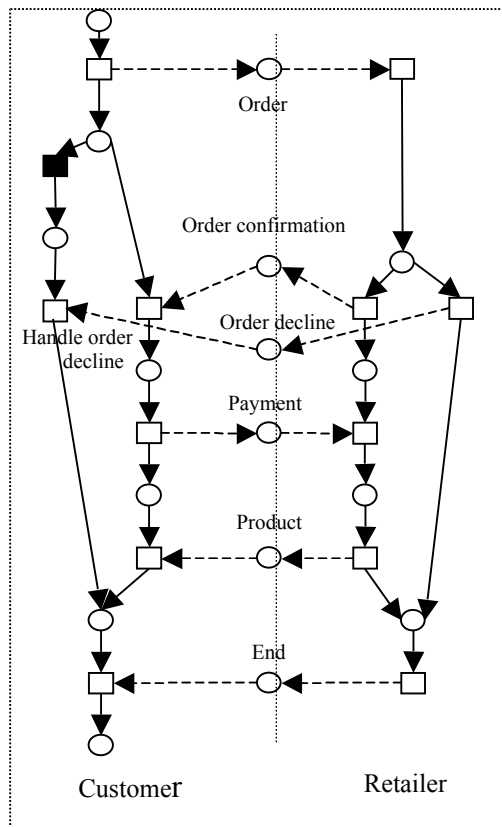


Figure 2. A change in customer sub workflow.

Comparing Figure 1 and Figure 2, it can be seen that in Figure 2, a new “black” transition is added in the sub workflow of the customer, which makes the customer workflow in Figure 1 not branching bisimilar to the customer workflow in Figure 2 after changing the new transitions to be silent. Such modification also makes the whole workflow in Figures 2 unsound. In Figure 2, the “black” transition can be fired before the retailer sends a response message back. In such a situation, the sub workflow of the customer is not able to handle all possible responses the retailer sends back. If an “order confirmation” message is received after the black transition is fired, the entire workflow in Figure 2 is in deadlock. In this scenario, branching bisimilarity concept enables us to check a sub workflow locally and decide if a change will affect overall soundness.

However, as can be seen in Figure 3, a seemingly similar modification in the retailer sub workflow does not affect the soundness of the entire workflow.

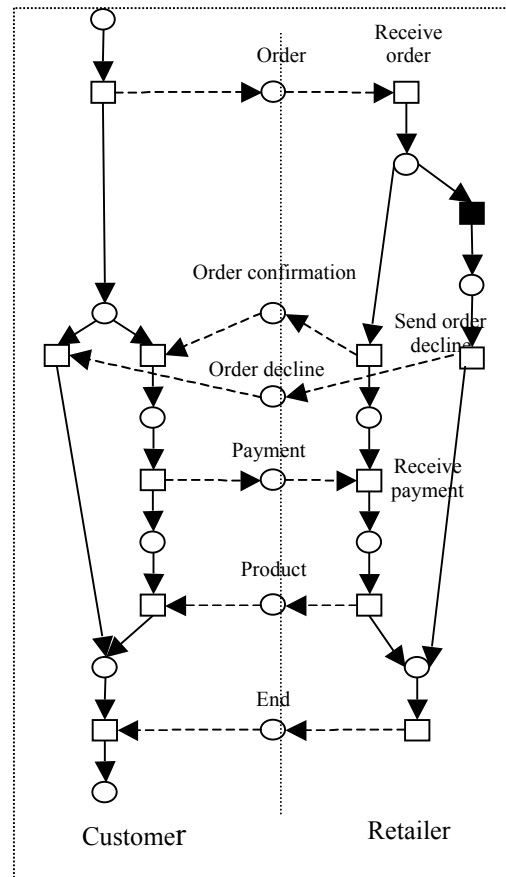


Figure 3. A change in retailer sub workflow.

It can be seen that similar to the workflow of Figure 2, a new ‘black’ transition is added to the retailer workflow in Figure 3 comparing with the workflow in Figure 1. It makes the retailer sub workflow in Figure 3 not branching bisimilar to the retailer sub workflow in Figure 1. However, such a modification does not make the overall workflow in Figure 3 unsound. This is different to the situation shown in Figure 2. It seems that the local criterion of branching bisimilarity and behavioral equivalence is too restrictive under this circumstance. If one takes a closer look at both figures 2 and 3, a subtle difference can be found. In Figure 2, the black transition is added before a transition receives message, whereas in Figure 3, the black transition is added before a transition sends message. This difference indicates that the direction of the message exchanged among the sub-workflows is an important factor that needs to be considered when we attempt to propose a more flexible local criterion. Definitions 1, 2 and 3 formulate a new local criterion called WF-net weakly equivalence for the P2P approach based on the concepts of labeled Petri net, WF-net model, workflow soundness, IOWF-net and workflow inheritance proposed in [4]. Readers are assumed to be familiar with these definitions and concepts. Further explanation of these definitions can be found in [4]. Definition 1 provides a function to

obtain the set of all transitions in a firing sequence. In Definition 2, consuming transitions of a sub workflow is defined; they refer to the set of transitions that receives message (or consumes tokens) from other sub-workflows. These two definitions will be used in Definition 3 when the new local criterion is formally defined. As the direction of the message needs to be taken into account, definitions 2 and 3 are formulated in an inter-organizational workflow context using the IOWF-net concept described in the last section.

Definition 1 ($con(\sigma)$). For any $\sigma \in T^*$ such that $\sigma = t_1, \dots, t_n$, $con(\sigma) = \{t_1, \dots, t_n\}$.

For example, for $\sigma = t_1, t_2, t_3$, $con(\sigma) = \{t_1, t_2, t_3\}$.

Definition 2 (Consuming transitions). Let $Q = (C, n, N_1, \dots, N_i, \dots, N_{n-1}, G)$ be an IOWF-net such that N_1, \dots, N_{n-1} are $n-1$ labeled P/T nets. $\forall k: 0 \leq k < n: N_k = (P_k, T_k, M_k, F_k, I_k)$. For any i such that $0 \leq k < n$ and $N_i = (P_i, T_i, M_i, F_i, I_i)$, the set $\{t \mid t \in T_i \wedge \exists c \in C: (c, I_i(t)) \in G\}$ is called the set of consuming transitions of N_i in Q , denoted $cs_Q(N_i)$.

To illustrate the concept of consuming transitions, consider the IOWF-net in Figures 3. The set of consuming transitions of the retailer sub workflow includes the transitions 'receive order' and 'receive payment'. The following Definition 3 formally defines the concept of weakly equivalence proposed in this research.

Definition 3 (Weakly equivalence of WF-nets in an IOWF net). Let $Q = (C, n, N_1, \dots, N_i, \dots, N_{n-1}, G)$ and $Q' = (C, n, N_1, \dots, N_i', \dots, N_{n-1}, G)$ be two IOWF-net such that $N_1, \dots, N_i, \dots, N_{n-1}$ and N_i' are $n+1$ WF-nets. $\forall k: 0 \leq k < n: N_k = (P_k, T_k, M_k, F_k, I_k)$. $N_i' = (P_i', T_i', M_i', F_i', I_i')$. N_i' is called to be weakly equivalent to N_i in Q , denoted $N_i' \equiv_Q N_i$, if and only if there exists two relation $\kappa_1 \subseteq |N_i, [I]| \times |N_i', [I]|$ and $\kappa_2 \subseteq |N_i, [I]| \times |N_i', [I]|$ such that for any $p, p' \in |N_1, [I]|$, $q, q' \in |N_2, [I]|$, and $a \in L$,

1. $(N_i, [i])R_2(N_i', [i])$ and $(N_i', [i])R_1(N_i, [i])$,
2. $q\kappa_1 p \wedge p|a\rangle p \wedge a \in L_v \quad _ \quad \exists q', q'': q \Rightarrow q' \wedge q' |a\rangle q \wedge q \kappa_1 p'$,
3. $q\kappa_1 p \wedge p|a\rangle p \wedge a = \tau \quad _ \quad \exists q: q \Rightarrow q' \wedge q' R_1 p'$,
4. $p\kappa_2 q \wedge q|a\rangle q \wedge a \in L_v \quad _ \quad \exists p'', p': p \Rightarrow p' \wedge p' |a\rangle p \wedge p \kappa_2 q'$,

5. $p\kappa_2 q \wedge q|a\rangle q \wedge a = \tau \quad _ \quad \exists p': p \Rightarrow p' \wedge p' R_2 q'$, and
6. For any q such that $p R_2 q$, $q R_1 p$ or $\exists p', q', \sigma \in T^*$ such that $con(\sigma) \cap cs(N_i') = \emptyset$ and $q|\sigma\rangle q \wedge q \kappa_1 p' \wedge p' R_2 q'$.

The concept of *weakly equivalence* is concerned with an old WF-net N_i and a new WF-net N_i' . Two relations R_1 and R_2 between the states of the old and new WF-nets are involved in the definition. Requirement 1 states that there exists relations R_1 and R_2 when N_i and N_i' are both in the state that only one token is on the input place 'i' (the meaning of the notation 'i' can be found in the definition of WF-net in [4]). Requirements 2 and 3, which deal with the first relation R_1 , demonstrate the ability of the new WF-net to simulate the behavior of the old WF-net. They state that before executing any number of silent transitions, the new workflow can reach a corresponding state of the old workflow regardless of whether an observable or silent transition is fired in the old workflow. Since $(N_i, [i])R_1(N_i', [i])$ and the new WF-net

N_i' can simulate any observable behavior of the old WF-net N_i , for any state of N_i , there is a corresponding state of N_i' in the relation R_1 . But for arbitrary state of N_i' , it is not necessary that there exist a corresponding state in N_i . Requirements 5 and 6, which deal with the second relation R_2 , demonstrate the ability of the old WF-net to simulate the behavior of the new WF-net. They state that after firing a transition (silent or observable transition) in the new workflow, there is always a state in the old workflow corresponding to the new state of the new workflow. Since $(N_i, [i])R_2(N_i', [i])$ and the old WF-net

N_i can simulate any observable behavior of the new WF-net N_i' , for any state of N_i' , there is a corresponding state of N_i in the relation R_2 . But for arbitrary state of N_i , it is not necessary that there exist a corresponding state in N_i' . Compared with branching bisimilarity, for a state of the new WF-net q such that $q R_1 p$, it can evolve into another state q' after executing a sequence of silent action. The concept of weakly equivalence allows the new state q' need not simulate all the behaviors of the corresponding marked, labeled P/T-net p , which is required in the concept of branching bisimilarity.

As mentioned, the customer sub workflow in Figure 2 and the retailer sub workflows in Figure 3

are both not branching bisimilar to the corresponding parts of the workflow in Figure 1. On the other hand, they both satisfy requirements 1 to 5 in Definition 3 when compared with the corresponding parts of the workflow in Figure 1. Since the entire workflow in Figure 2 is not sound but the one in Figure 3 is sound, requirement 6 of the definition is important when deciding if a change will affect overall soundness. Requirement 6 requires that for an arbitrary state of the new WF-net, either there is a corresponding state of the old WF-net which it can simulate, or it can reach a state that can simulate any observable behavior of the old workflow by executing a sequence of transitions which contains no consuming transitions. Consider the inter-organizational workflow given in Figure 1 and Figure 2, the customer sub workflow shown in Figure 2 is not weakly equivalent with the customer sub workflow given in Figure 1 because they don't satisfy requirement 6 of the definition. After the execution of the black transition, the customer sub workflow in Figure 2 is in a state where there is no corresponding state of the old customer workflow shown in Figure 1 in the relation R_2 . Moreover, it needs to fire the transition 'handle order decline', which is a consuming transition, to reach a state such that there exists a corresponding state of the old customer workflow in the relation R_2 . Obviously, it violates requirement 6 of Definition 3. On the other hand, the retailer sub workflow presented in Figure 3 is weakly equivalent with the retailer sub workflow in Figure 1 since they satisfy all six requirements of the definition. After the execution of the black transition, the retailer sub workflow in Figure 3 can fire the 'send order decline' transition, which is not a consuming transition, to reach a state such that there exists a corresponding state of the old retailer workflow in the relation R_2 . Furthermore, as mentioned, the overall workflow in Figure 3 is sound but the one in Figure 2 is not. In [14], it is shown and proven that it is not a coincidence that weakly equivalence leads to overall soundness in the examples above, and actually weakly equivalence concept achieves overall soundness when changes are made to one or more sub workflows.

It is obvious that weakly equivalence is a criterion that can be verified locally without the need to know other sub-workflows in the inter-organizational workflow. Moreover, comparing branching bisimilarity with weakly equivalence, weakly equivalence is considered more flexible because it can be easily seen that if there exists branching bisimulation relation between two WF-net, these two WF-nets are also weakly equivalent. As a result, weakly equivalence provides a more

flexible local criterion for the P2P approach by allowing internal workflow changes such as the adding of black transition in the scenario demonstrated in Figure 3. Such change is forbidden when using branching bisimilarity as the local criterion.

4. Conclusions

The principle of local criteria ensuring global soundness has provided a way to achieve overall soundness of an inter-organizational and at the same time ensuring privacy of sub-workflow is maintained. However, a comprehensive approach for flexible inter-organizational workflow design is still missing in the current literature. In this paper, a weakly equivalence concept has been proposed for the P2P approach to allow more flexible workflow modification within an organization. In the proposed approach it is not required to simulate all the behaviours of the corresponding workflow. However, as this new local criterion takes the direction of message exchange among different sub-workflows into account, a participant of an inter-organizational workflow will need to know the direction of messages connecting the sub-workflow before making changes.

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